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VERY SHALLOW WATER NOISE IMPACT OF OFFSHORE WINDFARMS. PARAMETERS TO BE CONSIDERED

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Abstract.

The noise impact of offshore wind farms is becoming the concern of conservationism. The paper presents a summary of those aspects that can influence on the shallow and very shallow water environment where many of the wind farms are located. As a first result the experience shows the important influence of the installation and decommissioning phases while the normal running activity has a much smaller impact on mammals and other fauna. Results are given with respect to European waters mainly. These results refer to the frequency content, the time duration, the peak and lowest levels to expect and the interaction with the background noise.. The knowledge of this set of data should be added to others from many different sites to form a data base that can become important in front of any future standardization

1.INTRODUCTION

It is largely known that the man made underwater noise shall have an effect on the marine life. The regulation of Ocean Noise, is a complex matter with, in many cases, international implications

This paper deals with offshore wind farms and their noise impact in shallow and very shallow waters. It is necessary to say that the wind flow over the sea surface present such a good characteristics, that the number and dimensions of the wind parks projected, and installed, in Europe and USA is continuously increasing. The noise impact of the series of turbines while functioning, and during the installation and decommissioning phases, needs to be considered, regulated and measured and mitigated. The anthropogenic origin of noise has to be distinguished from the natural noise originated in natural processes.

Only the man made noise need to be regulated. Political as well as economical barriers set a limit to such regulation. There is, nevertheless, some legal framework to start with. One example is the UN 1982 Convention on the Law of the Sea (LOS Convention), that covers problems related to pollution by radiation (e.l.m, thermal, radioactive, etc..), ¿Is the noise a pollutant of the marine environment?. The international law provides obligation for states in protecting and preserving the marine environment. According to the LOS, pollution is “The introduction by man, directly or indirectly, of substances or **energy** into the marine environment, including estuaries, which results, or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities". The LOS in its article 204 says: "States have a duty to endeavour to observe and measure, evaluate and analyze by recognized scientific methods the risks or effects of marine pollution directly or through the International Competent Organizations". It can then be concluded that the international Law is relevant for the issue of acoustic pollution. As a form of energy, sound falls under the definition of pollution of the marine environment.

The concern of many scientists on noise in the sea has produce a handful list of Reports, Books, papers, etc.., [1, 2, 3, 4]. About noise pollution, the greatest interest is on low frequency noise (below 1 kHz) because it can travel hundreds, even thousands, of km. from one country to another. This paper describes some characteristics of the noise involved in the offshore wind farms. First, is necessary to locate the wind farm in the shallow waters environment, with its specific limitations. Secondly it will review the main noise sources involved and their impact on marine species, if it is known. A third part will show how the noise is measured and how it can be mitigated, if necessary. Finally some conclusions will be proposed

The legal implications will remain outside the scope of this paper.

2. VERY SHALLOW WATER ENVIRONMENT

2.1. Very shallow waters sound propagation characteristics.

The very shallow waters are a part of the shallow waters region. They come limited by a depth of 30 m, and by the "surf line". By the above definition, any wind park, in this time, would be installed in very shallow waters. In fact, is perhaps more correct to define the very shallow waters as that part of the sea in which the water column becomes a small number of wavelengths. In these circumstances, the wave nature of the sound will decide if the sound perturbation will, or will not, propagate; this is equivalent to ask if there is enough number of modes for the mechanical perturbation to propagate. The number of modes depend on the depth and also, on the bottom quality. Those modes with horizontal angle of propagation smaller than the critical angle will go to a distance lower than several times the water depth.

The natural random fluctuating factors in the very shallow waters scenario, increases the difficulties involved in the sound signal propagation. This is one more reason to evaluate the sound propagation as a statistical process and not as a deterministic one. To this random nature of the sound contributes the rough profile of the water surface (in some way the roughness of the bottom also). The sound is reflected, dispersed, to a great number of directions; the waves move up and down making the process of detection unpredictable. The sound becomes also absorbed by the bubbles field created by the wave passage, [5].

2.2. Underwater life.

It is important to know the marine ecosystem that could be damaged by the installation of a wind park. This information would imply to identify the marine life: mammals, fishing, reptiles, seaweeds, etc.., as well as to be ascertain of the consequences of the loud noise on the fauna, (i.e., ears damage, internal tissue damage, even death, etc..) and the influence of the extra noise, by itself, on other marine life processes; masking of the communications activities [6], blindness on feeding, avoidance of the predators, lack of resting, mating, and displacement of species that could explain drastic catch reductions in fishing industry. What about the noise effect on the food chain? Experiments in aquariums have shown that the noise has influence in the reduction of the growth and reproduction on a variety of marine organisms. When these organisms are part of the food chain, the food chain is disrupted, [7].

3. OFFSHORE WIND FARM. NOISE SOURCES.

3.1. Ambient Noise.

While there are now 30 years of experience in assessing and meeting environmental challenges associated with land based wind installations, little is known of the effect of offshore wind farms.

Underwater noise is multi-dimensional. Underwater noise cannot be characterized by a single measure, on the contrary, a number of different factors must be considered: frequency, bandwidth, duration, intensity, duty cycle, rise time, temporal structure; also the noise is a direct function of the receiving point and the path from the source (the propagation losses depend on the water depth, water temperature profile, bottom absorption and its reflective properties: one order of magnitude can be the total influence of those local conditions). These variable qualities of the underwater noise explain why a statistical representation of it is necessary

Ambient noise originates from many different sources that differ in frequency and level. Ambient noise depends on the weather: wind speed (wave height), rain, ice; also on marine life, seismic activity, water depth, type of sea floor, time of the day, and time of the year (batythermal conditions), and, finally, on man made activities: transport (plains, helicopters, ships), dredging, drilling, civil works, exploration and exploitations of mineral resources, geophysical surveys, sonar emissions, communications and warning, explosions, marine research..

Ambient noise is the background noise plus the man made noise. The ambient noise, as a particular kind of underwater noise, shows all its statistical characteristics (time history). The ambient noise has to be measured, and when possible to identify which origins, or which are the sources, natural and/or man-made (i.e. local or distant shipping). Figure 1 shows, as one example, the ambient noise measured in one specific wind farm site off the coast of Spain (green line) and it is compared with the noise from a wind park at two different steps. It can be noticed both the ambient noise broad spectrum and the noise from the wind farm. It can be noticed how those spectra overlap the frequency ranges used by important marine fauna to ear and communicate, [2,8] .

3.2. Installation and decommissioning.

While the wind farm is being installed the main disturbing noise comes from three different sources: transportation noise from the auxiliary ships when moving and operating (fully loaded vessels and/or towing or pushing vessels, present peak levels in the 5Hz-500 Hz range), the noise coming from the hammering process of the wind turbine basement; another source of noise comes from the dredging involved in creating the trenches where to lay the cables connecting each of the wind towers, of the farm, with the control station and from this station to shore. The three main types of noise sources produce a sound perturbation with a great part of the energy concentrated in the low frequencies range. Also, the environment affected is located in the shallow or very shallow waters that are the most biologically productive. The effect on humans is also important to know during installation and decommissioning. In these cases to reach peak levels greater than 145 dB can result in irreversible damage, [9].

The noise from auxiliary shipping is relatively well known in underwater acoustics. The analysis must be then concentrated on the turbine basement construction. In all cases the basement (monopile or other) is driven into the sea floor by an impact piling procedure, with the help of drilling when hard rock is found. Figure 1A shows a typical energy content of some piling impact, [13]. The sonar will also be active. Sonar is needed evaluating the quality of the bottom sediments, and to accurately control the water depth [10].

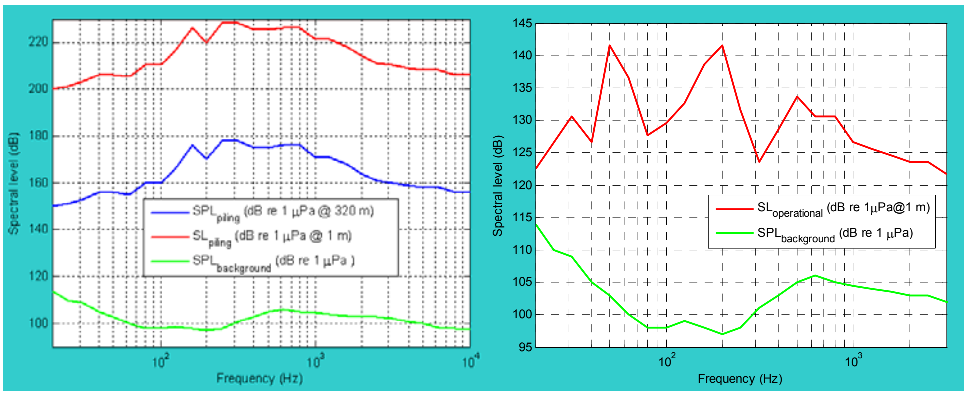

Figure 2. A) Spectrum of a piling impact as a source level and at 320 m from the source. B). Spectrum (Source level) of the noise during operation. Both results are compared with ambient noise (green curve), [14].

As a summary, data from previous experiences says: the piling process is the most important within the range of 10 Hz to 20 kHz. For frequencies below 1 kHz most of the acoustic energy, from the piling process, is concentrated. It also can be identify some tonal data at specific frequencies. In the range 1 kHz to 4 kHz the piling noise shows the lowest difference with background and consequently this band will the first to be masked by background noise; in the remaining range (4 kHz to 20 kHz) the level increment can go up to 60 dB above background. During decommissioning, detonations of explosives are likely to occur, and then information on this type of sources is necessary, [11]. Due to the very shallow water environment, is important to select the receiving measuring point, because points located at equal distance (down or up water), can give levels differences of 10 dB, or more.

3.3. Noise during operation.

The wind causes the blades, of each single platform, to move and rotate. The wind is continuously varying in modulus as well as in direction (a direction or a range of directions is generally predominant). It varies its annual mean value; it changes also with the season (seasonal), with passing weather systems (synoptic), changes on daily bases (diurnal), and from second to second (turbulence). The available power from a wind flow is proportional to the area swept by the blades and to the third power of the wind speed,

$$P_W = \frac{1}{2} \rho \pi R^2 c_w^3$$

where ρ is the air density, R de length of the blade and c_W is the wind speed. Rapid wind fluctuations can translate to dramatic short term output variations. The grouping of many turbines, in a wind farm, has the statistical effect of aggregation, and in consequence, a marked smoothing effect. For this to be true, it has been assumed that the individual short term motion fluctuations are uncorrelated between turbines, then the variation of the aggregation output will fall with the law $1/\sqrt{N}$, being N the number of turbines in the group. On the other hand Betz's Law sets a limit to the maximum efficiency in the conversion of kinetic into mechanical energy that a wind tower can afford; this limit is 59%, [13].

The noise generated by a turbine Figure 1B, in production regime, is of two types: mechanical, from gears, and aerodynamical, from the turbine blades. In some cases the mechanical is partly tonal noise and it predominates, but modern designs are reducing this type of tonal noise.

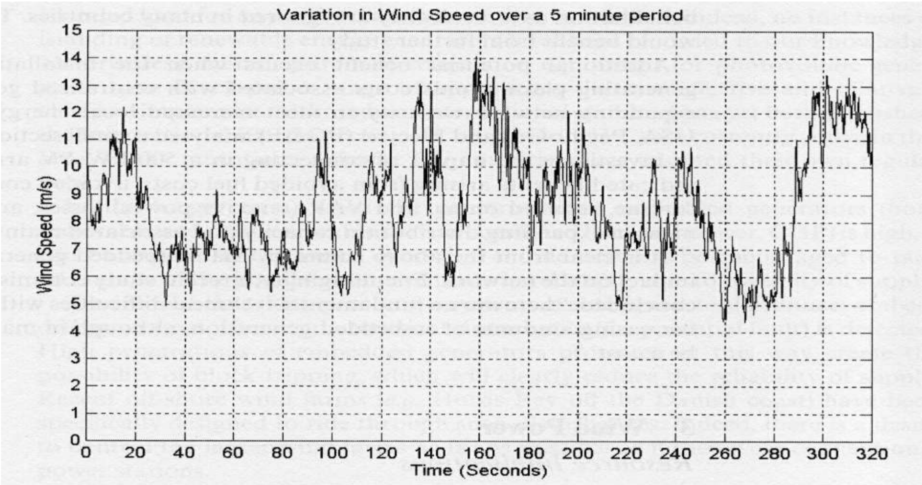

Figure 2. Wind modulus variation in a 5 minutes period. [3]

The aerodynamical noise is broadband in nature, very similar to background noise, and it increases with increasing turbulence associated to roughness of the basement surroundings (for offshore wind farms it is fortunate that the sea surface roughness is very small). Mechanical noise is predominant at low frequencies: 100 Hz – 500 Hz, Figure 3. Aerodynamical noise predominates around 1-2 kHz and expands to either sides within the band of 650 Hz to 8 kHz. The sound transmitted from the tower into the sea will predominate over the sound from other origin (i.e. airborne sound). The sound transmitted through the tower structure, before it comes into the water is further attenuated by the interfacing effect between sandwiched materials (modern designs reduce the coupling and resonance effects between inside mechanisms and the tower walls; the result is a radiated noise emission fairly low, so: for frequencies above 100 Hz, the sound level is likely to be below ambient noise. For frequencies below 100 Hz, the mechanical noise increases, but at distances of half a km, and for wind speeds 8 m/s, lies between 75 to 95 dB. The vibration levels dominate at low frequencies (up to 0.5 kHz). Above 500 Hz, and below 10 kHz, the levels rapidly fall off at 10 dB/octave rate.

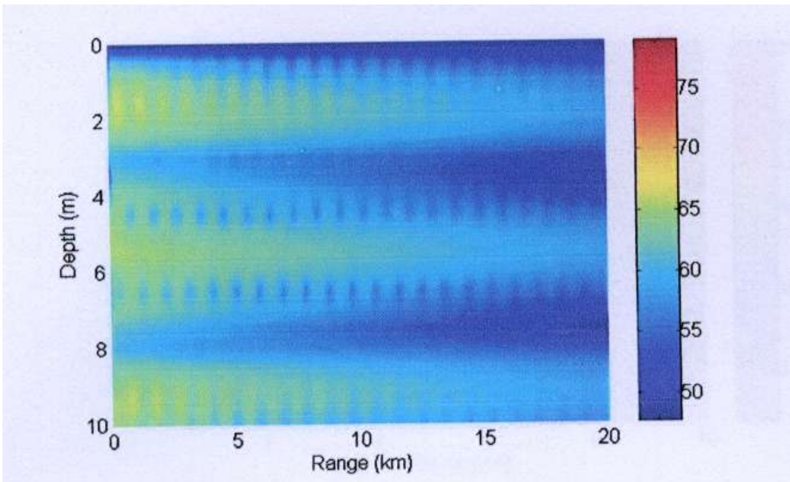

Figure 3. Radiated 400 Hz signal by a vibrating basement into the water. The levels are dB re 1μPa, [17]

Figure 3, shows a 400 Hz modelled signal radiated into the water by a vibrating wind turbine tower. In some specific cases, for fairly good propagation conditions the sound radiated can reach several Km. The graph shows the signal level variation with depth. In this example the fish can heard the vibration down to 5 Km. This is very exceptional because in other frequency ranges the radiated levels fall below the fish audible threshold, at only few meters from the basement, [17].

4.MEASUREMENTS AND MONITORING

A system, with sufficiently wide bandwidth, that could continuously measure the noise output from the turbines can be a magnificent start. By software the measures can produce, very easily, information on the frequency content, and the level broadband or at any narrower band of interest. By software also, if some levels are surpassed, to prevent unwanted consequences, different actions could be triggered. Part of the monitoring system can be a hydrophone, or several sector looking hydrophones mounted on the turbine basement, below the surface. Those sensors can carry out a permanent control of the ambient noise; any abnormal sound, while normal operating, means a problem to watch on. Depending on the type and extension of the wind park, the permanent hydrophones in each turbine basement, or in any selected ones, can be substituted by hydrophone arrays or by permanent listening systems in buoys. The monitoring can be completed by using air microphones and accelerometers to check permanently the own noise and vibration status of the tower, to compare it against a data base in which the parameter can be the wind speed. This data can be of use in some other type of studies, i.e., to relate wind speed with background noise and point of measurement. Records should be kept on all the events giving as much information as possible.

Nowadays the help of any reliable software modelling underwater sound propagation can become of main importance. There is, in the literature, many examples of software easy enough to be implemented to model the situation and to check for any unexpected situation, [14]. These models are also needed to pre evaluate the noise risks at any point, in or out of the wind farm and along the life spam of the wind park, considered in the projected Environmental Impact Assessment, EIA. The use of models has to be carefully done in evaluating the effects of noise at very close ranges of the high intensity sources (i.e., hammering or detonations); in such circumstances the direct measurement is the only reliable way to know the harm nature of the noise

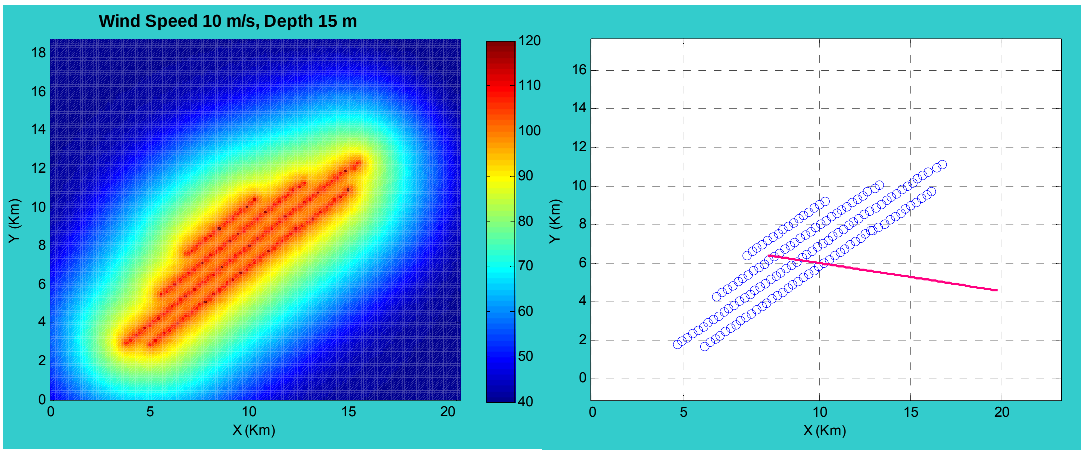

Figure 4. Geometry of a wind park. The red line shows one of the transects selected to monitor the noise signal during operation. [14].

Other important data is to know the area affected by the noise, and to monitor it, but this area as I have said, somewhere in this paper, is not a fix parameter because it depends on many variable factors; so is again time to have a statistical measure, such as the area affected by a selected percentage of the time (i.e., 5%, 10%,). To achieve such knowledge the monitoring needs to be carried out through a line, or set of lines, or transects, trespassing the park area up to the distance in which the noise level will descend below the estimated dangerous level, Figure 4. This kind of monitoring will help in identifying the sources from outside the wind farm that are, also, contributing to the noise impact.

The measurement of this noise need first to select the measure point, or set of points inside and outside the wind park, then comes the selection of the sensors to be used (microphones and hydrophones), the wind speed data (value, direction, standard deviation), wave height (sea state), selected time frames, equipment conforming the relevant standards, and calibration on-site (prior and post measurements), Figure 5. Is very convenient, when possible, that the monitoring should always be carried out at some specific wind speed (the speed of 8 m/s is becoming an accepted reference value), [14]. The noise impact on the environment also is the interest of some software initiatives, to improve the Environmental Impact Assessments, EIA, and the environmental management and decision making procedures, [15].

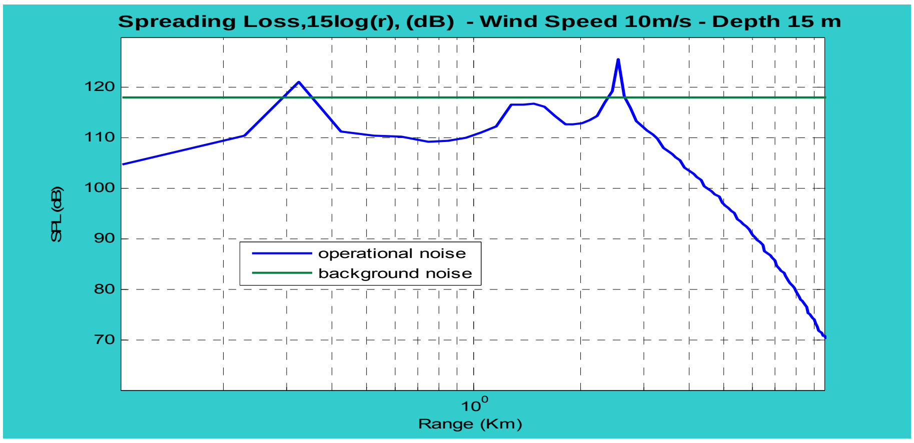

Figure 5. Expected noise level along the transect (red line) of Figure 4.

5. MITIGATION MEASURES

Mitigation measures are numerous with varied efficiency. In Denmark, large bubbles curtains around the pile have proved useful in reducing noise levels by 10 to 30 dB. Other example is the experience of pile operation during the construction of the Hong Kong airport at Sha Chau, in which pile driving and construction where isolated with bubbles curtains. Those authors give 8 – 10 dB reduction in broadband sound levels in the range 400 Hz to 800 Hz. This reduction increases up to 15 – 20 dB in the range 1600 Hz up to 6400 Hz. Depending on the water depth the density and diameter of the bubbles could differ, [16].

One of the most practical measures to undertake is to continuously monitor the noise levels. The results, from fixed and mobile hydrophones, will dictate the most practical measures combining efficiency and care for the environment.

The installation and decommissioning will last for several months while the working life of the farm last for 25 to 30 years. So the monitoring during functioning is the most advisable activity, not only to check the noise, but also the evolution of marine life. The long term impact is, for many reasons, the most important to consider.

6. CONCLUSIONS

Current research shows that although wind farms noise, in the production phase, should have short terms effects on marine life, most fauna affected show habituation to the noise.

High levels produced by piling and transportation or activities related, along the installation phase, only show short term effects on the bio environment. So, only piling, during installation, and detonations during decommissioning, are able to produce noise that could cause harm in the marine life, provided the fauna affected would stay within the range of several hundreds of meters. Outside that range the effects would be small.

While there are important quantities of data from all related activities around the high number of offshore wind farms to be installed in all the continents, it would be convenient to gather all these information in one unique body that could help, in the field of acoustics, in normalizing the measurements and the monitoring. Sound can become a pollutant, for sea activities and sea life, which under the sake of a better life is mandatory to keep it under control.

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